Performance Improvement of Power System Stabilizer for a Single Machine System Using Hybrid Controller Approach

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Abstract: In most of the cases, a single controller, either it be a simple basic PID controller or other controllers like Fuzzy Logic controller, Artificial Neural Network Fuzzy Logic controller is sufficient for controlling a specific parameter. In contrast to this possibility, there can be a situation where the single controller may fail to satisfactorily control the required parameter to required value. In such situations, a hybrid controller approach by using one controller in conjunction with another controller can be helpful. Controlling burden is shared by the two controllers obtaining optimum control. This paper proposes a hybrid controller approach using a PID controller and in conjunction with Fuzzy Logic Controller. A single machine system is implemented with various magnitude of loads and simulated using MATLAB® Simulink software. Results of voltage deviation and frequency deviation with step load and various steps of load is compared with fractional order PID controller.

Index terms: PID controller, Fuzzy Logic Controller, Power System Stabilizer (PSS), Automatic Voltage Regulator (AVR), Single Machine System, Hybrid Controller, Cascade Control.

I. INTRODUCTION

The whole power system mainly consists of generation, transmission and distribution of electrical energy which operate with some specific parameters were maintained to be constant irrespective of load applied on power system. Such parameters include voltage profile, frequency. So, it is necessary to maintain the voltage and frequency at rated values. These are simple parameters to control but with a constantly changing load on power system, it is difficult to maintain at rated value within the tolerant limits for both voltage and frequency. Generally, at the generator, Automatic Voltage Regulator (AVR) and Power system stabilizer (PSS) are used for voltage control, and High-speed governor system of steam valve control for frequency is used. The Automatic Voltage Regulator have little effect on change of frequency for a machine connected to infinite busbar. Governor system used to control steam input has little effect on change of terminal voltage. This is not case for single-machine. With change in load, the armature reaction in the synchronous machine varies in magnitude. So, a fast-acting excitation system is required to change the excitation given to the synchronous system changes according to the armature reaction in a way to neutralize it. Several controllers have been developed for the fast and accurate acting of the Automatic Voltage Regulator (AVR). In both have some effect on each other. In [1], Graham J. W. Dudgeon has investigated Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS) together for the first time. Here the effect of fast acting exciter system on decreasing power system oscillations and also the Power System Stabilizer (PSS) can reduce transient stability by overriding the voltage signal to the exciter as well as increasing oscillation stability. By using Bode plot, frequency response and analysis of Automatic Voltage regulator (AVR) and Power System Stabilizer (PSS) have been presented. In [2], Dhanesh K. Sambariya has proposed a Proportional Integral Derivative (PID) controller-based Power System Stabilizer (PSS) tuned using Bat Algorithm.

The PID controller design was considered with an objective function based on square error minimization for enhancing small signal stability. The robustness of the proposed controller is tested with an eight-plant configuration and wide operating conditions like unlike loading and system configurations. In [3], Lakhdar Chaib, proposed a novel robust Power System Stabilizer (PSS) which is based on a fractional order PID controller using a new metaheuristic optimization Bat algorithm inspired by ecological behaviour of the bats to improve power system stability. The optimization criteria is based on performance indices (PI), including Integral Absolute Error (IAE), Integral Squared Error (ISE), Integral Time-Weighted Absolute Error (ITAE). In [4], Saptarshi Das has analysed Fuzzy Logic Based controllers considering several combinations of controllers by groping the three actions of PID controller such as Proportional, Integral, and Derivative actions combined with fuzzy inferencing in different forms. Fractional order rate of error and fractional order integral control of signal have been put forth in this paper. Input and output scaling factors along with integral differential operators are tuned using real coded genetic algorithm (GA).

In [5], Prakash K. Ray presented a paper for improvement of stability of a single machine connected to infinite bus system by designing a fractional order Fuzzy PID controller-based Power System Stabilizer (PSS). Firefly algorithm which is a bio-inspired algorithm was employed for tuning the parameters of proposed fractional order fuzzy PID controller. Its robustness is tested for various load conditions such as for an application of step load, for varying steps of loads and for a random load change. Performance Indices (PI) like maximum overshoot, settling time and Integral Squared Error (ISE) were calculated.

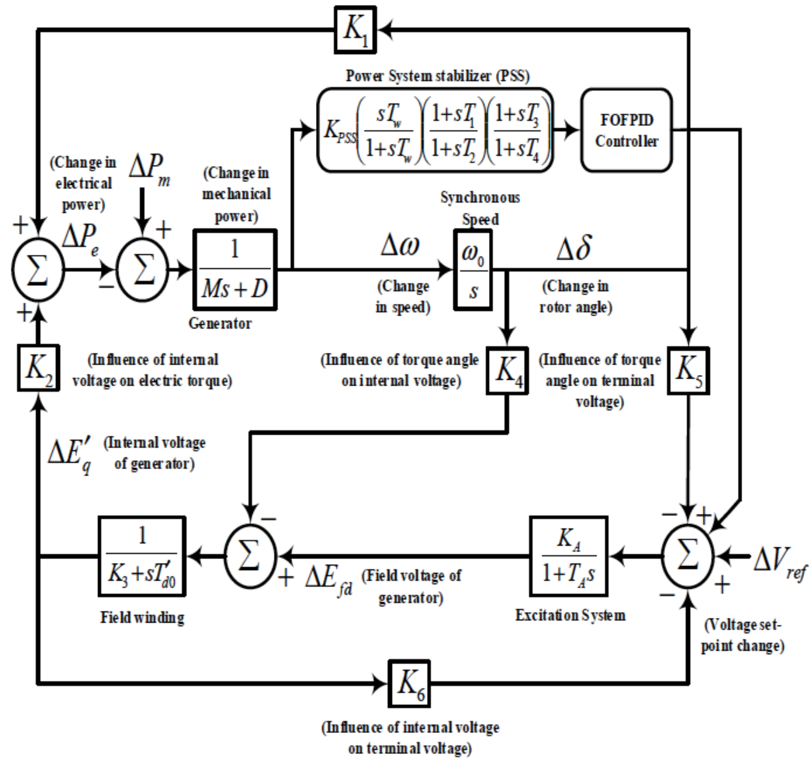

Fig 1: Linearized Heffron-Phillip model of SMIB system

The fractional order PID controller is simulated for a standard model of linearized Heffron – Philip model. The controller input is taken as the change of rotor speed and rate of change of rotor speed for the power system stabilizer and fractional order PID controller. The summation of the resultant signals like change in rotor angle, controlling signal obtained from the Power System Stabilizer and the fractional order PID controller, voltage point change and the voltage reference voltage is given as a input to the excitation system. This feedback loop controls the generator excitation in-turn controlling voltage at the terminals of the generator compensating the armature reaction and maintaining it at required rated value.

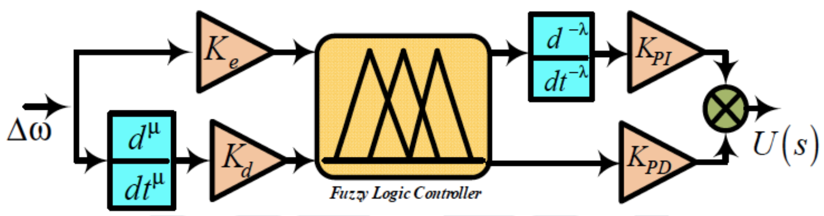

Fig 2: Fractional Order Fuzzy PID Controller

Figure 2 shows the controller block diagram used in the Linearized Heffron-Philips model. The optimum values of gains $K_e = 1.88$, $K_d = 0.44$, $K_{PI} = 1.44$, $K_{PD} = 1.93$ are computed using the firefly algorithm.

II. PROPOSED SYSTEM

The proposed system consists of a single machine system connected to load. The main synchronous machine is supplied with excitation from an auxiliary synchronous machine generally called as a exciter which is places on the same shaft as that of the main synchronous machine. Various loads are on the main synchronous machine that operate i.e., come on-line and go off-line at some specific time intervals to mimic the actual variation of load on the generator in real scenario.

The terminal voltage positive sequence signal is taken from the generator terminals. That signal magnitude is given to the proposed The Fuzzy Logic controller takes that two inputs and gives its output according to the rules defined to in its rule base. PID controller which is in conjunction with the Fuzzy Logic Controller takes the output signal from it and controls it to a required output value to come out from the PID controller.

This overall signal output from the PID controller controls the excitation signal for the exciter. This action results in the change of the terminal voltage of the exciter. This exciter terminal voltage changes affect the excitation given to the main synchronous generator which in-turn changes the terminal voltage of the main synchronous machine.

A. Proposed Controller Structure

The proposed controller has a two-stage controller approach in which the Fuzzy Logic Controller receives two signals. One is a voltage magnitude signal and other is the rate of change of voltage signal. Based on the input signals received, the Fuzzy Logic Controller produced a output following the rule base.

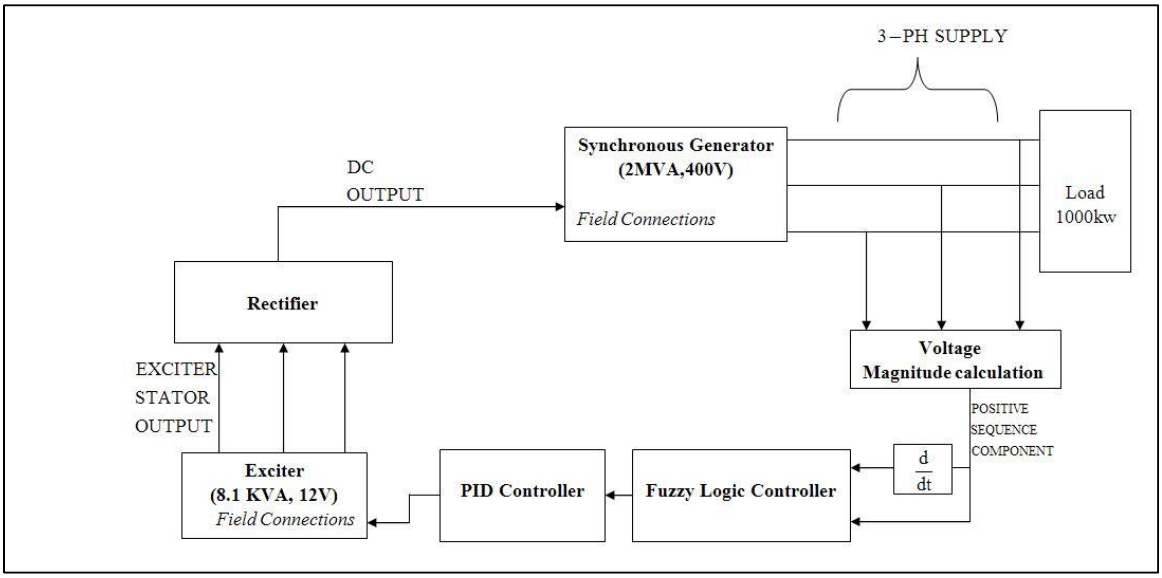

Fig 3. Proposed System Block Diagram

This signal is further controller still making the controlling signal more near to what needed to achieve a constant voltage signal for the synchronous generator. There are totally seven membership functions used in the Fuzzy Logic Controller ranging from -1p.u. to 1p.u. which needed to be given as the output signal.

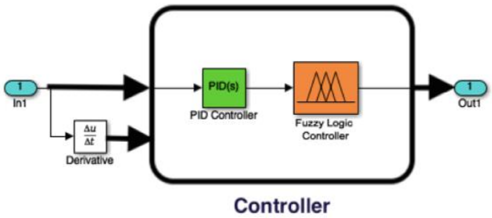

Fig 4: Hybrid Controller Block Diagram

B. Membership Functions and Rule Base

There are 7 membership functions used in the Fuzzy Rule Base with Triangular Membership function with Mamdani Fuzzy Inference Technique. The triangular membership functions for error and rate of change of error are shown in figure 5. These membership functions are all weighted equal with respect to each-other.

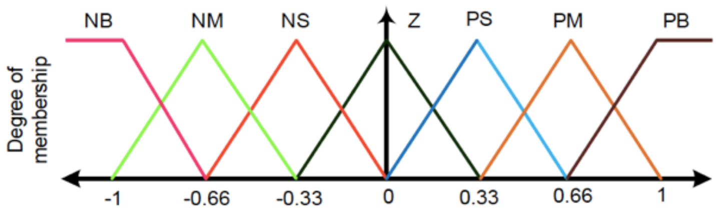

Fig 5: Triangular Membership Functions

C. Fuzzy Rule Base for Error and Rate of Change of Error or Voltage

Table 1 shows the rule base for the Fuzzy Inference system used to compute the output of the Fuzzy controller. These include the linguistic variables such as Negative Small, Negative Medium, Negative Large, Positive Small, Positive Medium, Positive Large, and Zero.

Table 1. Rule Base for Fuzzy Inference System

dv/dt / **V**	**NL**	**NM**	**NS**	**ZS**	**PS**	**PM**	**PL**
NL	PL	PL	PL	PL	PL	PM	ZS
NM	PL	PL	PM	PM	PM	ZS	NS
NS	PL	PM	PS	PS	PS	NS	NM
ZS	PL	PM	PS	ZS	NS	NM	NL
PS	PM	PS	NS	NS	NS	NM	NL
PM	PS	ZS	NM	NM	NM	NL	NL
PL	ZS	NS	NL	NL	NL	NL	NL

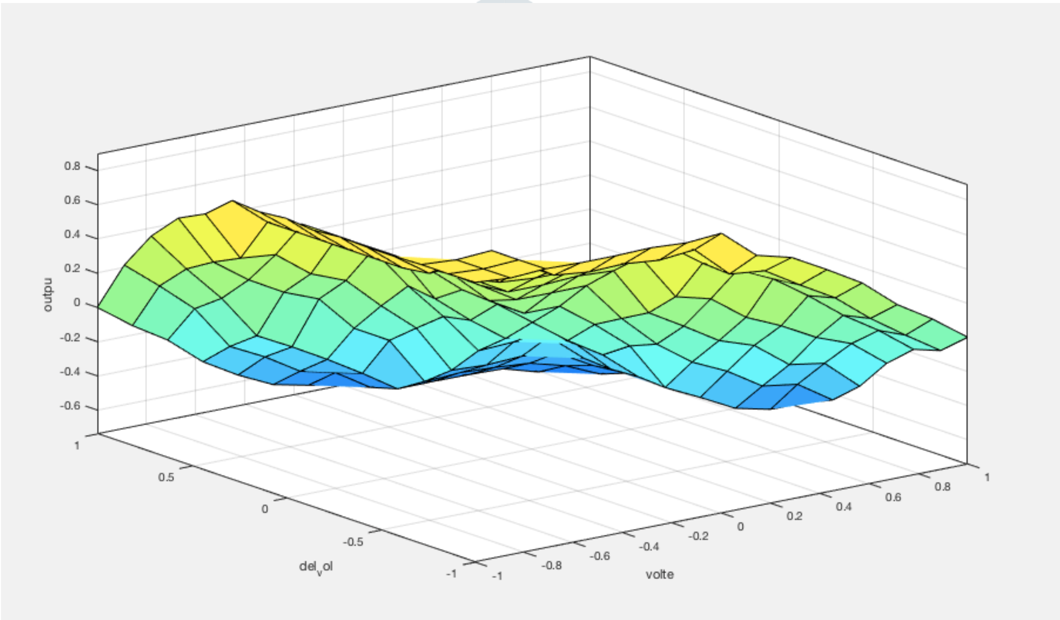

Fig 6. Surface View of the Fuzzy Rule Base

D. Simulation Parameters

The system developed in MATLAB consists of two synchronous machines one acting as a main synchronous machines and other acting as an exciter for the main synchronous machine. There are five loads of different rating applied upon the synchronous generator to carry out the tests for the effectiveness of the proposed controller. Table 2 shows the values of parameters used for the simulation.

Table 2. Proposed System Parameters

S. No	**Parameter**	**Value**
1.	Voltage	400 V
2.	Power	2 MVA
3.	Frequency	50 Hz
4.	Load 1	1.6 MW
5.	Load 2	0.2 MW
6.	Load 3	1.2 MW
7.	Load 4	0.6 MW
8.	Load 5	1.8 MW

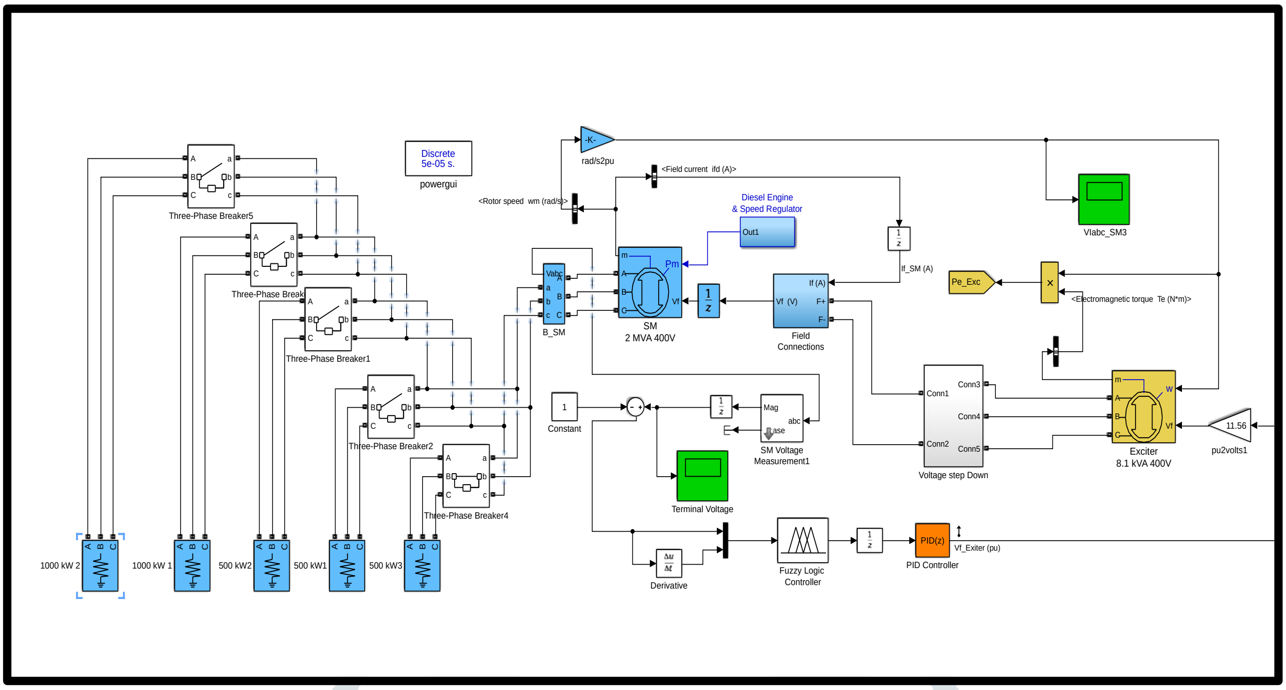

Fig 7. Proposed Simulation Diagram for Hybrid Controller

III. SIMULATION RESULTS AND DISCUSSIONS

This section shows the of the same. results obtained by MATLAB Simulation of the Hybrid Controller Approach for a single machine system having various loads and the performance analysis.

Case 1: Variation with step load change

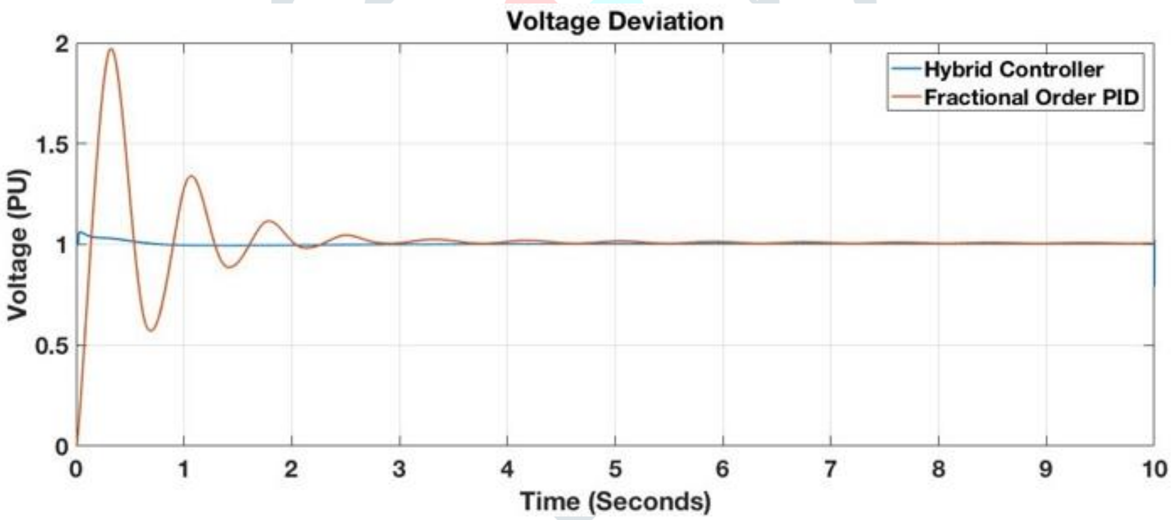

Fig 8: Voltage deviation comparison of Fractional Order PID and Hybrid Controller

Figure 8 shows the deviation of voltage from its reference voltage i.e., 1 P.U when the generator is subjected to a load of 1 P.U. The existing system of Fractional Order PID controller takes almost 3 cycles to attain steady state and value of 1 P.U whereas the proposed Hybrid Controller setup attains steady state within a fraction of cycle. Also, the voltage rises to 100% over the reference value for Fractional Order PID controller and Hybrid Controller rises only 8% over the reference value.

Figure 9 shows the deviation of frequency from the reference value. In case of Fractional Order PID controller, it takes almost 7 seconds and several swings of rotor to attain close to reference value and takes approximately 4 seconds for deviation with steady state error of 1%. In case of proposed Hybrid Controller, it takes only the first swing to attain the reference value without any deviation and takes only a second for same.

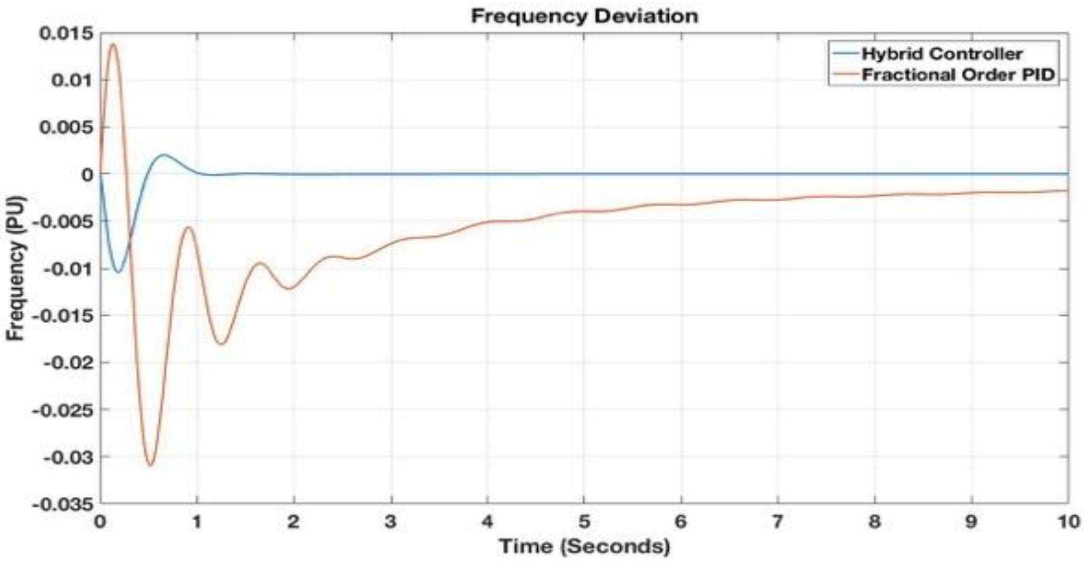

Fig 9: Frequency deviation comparison of Fractional Order PID and Hybrid Controller

Load Variations in Steps:

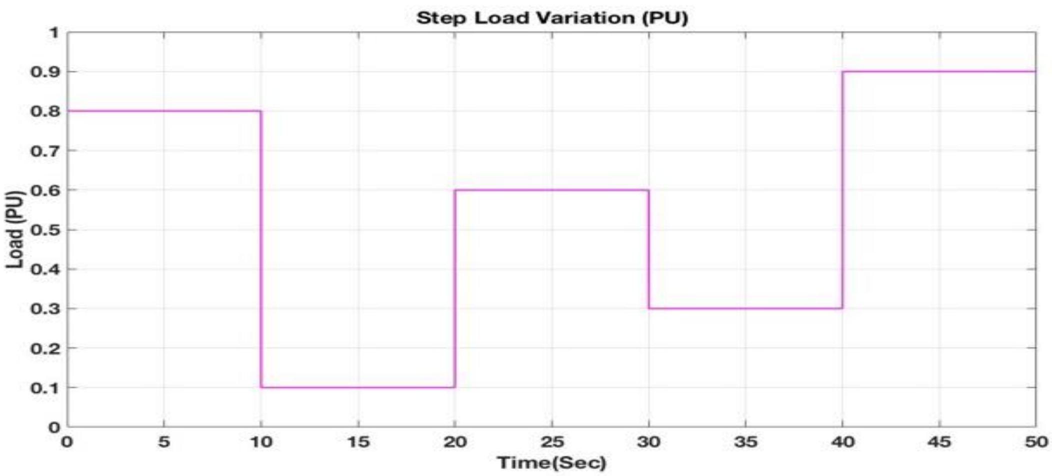

Fig 10. Graph showing variations of load with respect to time.

Table 3: Variations of load with time intervals

Time (Sec)		Load (P.U)
From	To	
0	10	0.8
10	20	0.1
20	30	0.6
30	40	0.3
40	50	0.9

A load of 0.8 P.U is applied on to generator from starting to 10 seconds of operation. A load of 0.1 P.U is applied on to generator from 10 seconds to 20 seconds of operation. A load of 0.6 P.U is applied on to generator from 20 seconds to 30 seconds of operation. A load of 0.3 P.U is applied on to generator from 30 seconds to 40 seconds of operation. A load of 0.9 P.U is applied on to generator from 40 seconds to 50 seconds of operation.

Case 2: Variation for various step of load changes

Figure 11 shows the comparison between the terminal voltage variation of Fractional Order PID and Hybrid Controller setup for various load changes in steps. These step load values are show in figure 3. In figure 4, we can observe that existing Fractional Order PID controller have some oscillations (nearly 3 cycles) before settling to the final value and taking approximately 3-4 seconds to attain final value. Hybrid controller makes no oscillations attaining the final value only in a fraction of cycle duration.

It can be observed that the Hybrid Controller setup maintains near to reference value unlike the Fractional Order PID controller which changes its final value based on load changes not maintaining a steady final value.

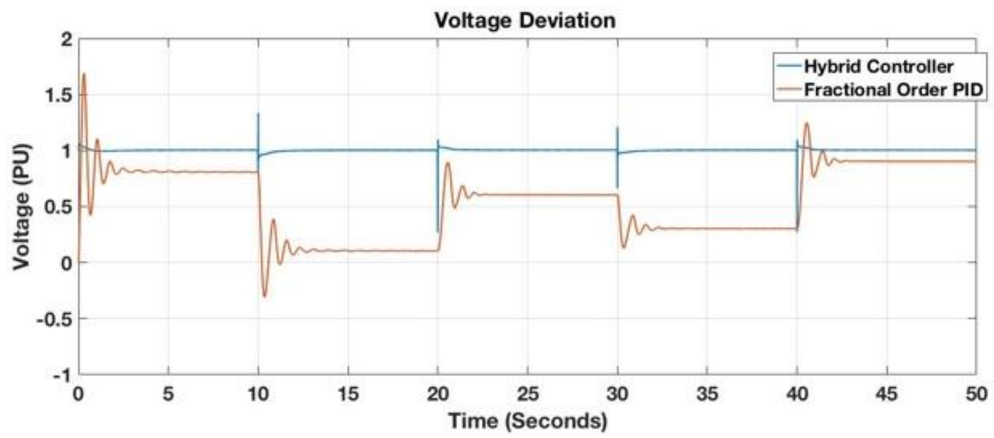

Fig 11: Comparison of Voltage deviation for various step load changes

Figure 12 shows the comparison between the frequency deviation for Fractional Order PID Controller and Hybrid Controller for various step load changes as shown in figure 3. In figure 5, we can observe the Fractional Order PID controller takes approximately 3 swings before for it to attain a steady rotor angle whereas the proposed Hybrid Controller takes only 1 swing before attaining a steady rotor angle. The time taken for the rotor to attain steady angle is less for proposed Hybrid Controller and more for the Fractional Order PID Controller.

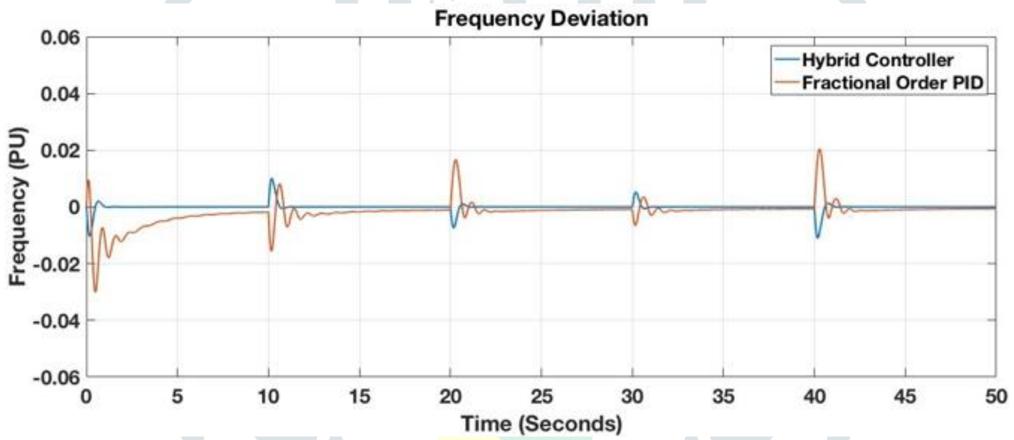

Fig 12. Comparison of frequency deviation for various step load changes

IV. CONCLUSION

The simulation is performed in MATLAB Simulink software on the system shown in figure 7 by applying various loads. By the use of PID controller and Fuzzy Logic controller both in conjunction, better voltage regulation is achieved, overshoot is reduced to low value and settling time is reduced. The same conclusion can be drawn from the results shown.

Table 4. Comparison of performance parameters

Parameters	FO - PID	Hybrid Controller (Fuzzy – PID)
Rise Time	0.2 Sec	0.01 Sec
Settling Time	2.8 Sec	0.6 Sec
Peak Time	0.48 Sec	0.02 Sec
Maximum Overshoot	2 Pu	1.08 Pu
Number of swings	7	1

Future Scope:

The extra overshoot observed in some cases can be still reduced to a even low value by use of Neuro-Fuzzy Logic or Artificial Neural Network trained by Deep Reinforcement Learning.

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